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The relation of dikes to schist layers, the fact that lit-par-lit injection tends to neutralize chemical and physical differences between the magma and the invaded rock, the probable low temperature of the granite, and the fact that positive evidence of absorption or assimilation on a large scale is lacking, all support the belief that physical displacement and not assimilation was the primary process by which the forward movement of the magma was accomplished. The possibility that large blocks of roof in the areas of harder quartzite have been engulfed in the magma, and that this process was in these areas an important one, must remain an open question. In the main it is considered that the magma actually displaced the rocks either along great rifts or by pushing the yielding softer rocks before it into recumbent folds.

ON THE FOSSIL ALGAE OF THE PETROLEUM-YIELDING SHALES OF THE GREEN RIVER FORMATION OF COLORADO AND UTAH

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In the region extending from northwestern Colorado west into Utah and north into Wyoming, there are great areas of, generally, carbonaceous shales, which, in places, exceed 3000 feet in thickness. Scientific, as well as economic interest has been aroused in these shales, because they have recently been discovered to yield petroleum when subjected to destructive distillation in closed retorts. These shales are typically dark brown in color, very fine grained, hard, firm, tough and compact, except where weathered into thin, more or less curled and brittle laminae. Surfaces long exposed to the action of the weather bleach to whitish or yellowish gray. Some beds in the series of these shales already examined are so highly carbonaceous that they closely resemble compact lignite in appearance and burn readily when heated; other beds contain rather high percentages of finely divided mineral matter.

When freshly broken, the rock gives off a distinctly bituminous odor, but, so far as observed, it contains no free oily compounds, although nodules and particles of a substance resembling asphaltum, but insoluble in the usual solvents of that substance, are sometimes found; and, as already noted, petroleum is always found among the products of its distillation.

Careful study of the stratigraphic relationship of these shales by the U. S Geological Survey, has shown them to belong to the Green River

Formation of Eocene time. This formation is widely known in some of its Wyoming phases for its richness in fossil fish remains.

About a year ago, samples of the shale from near De Beque, Colorado, and, later, from other localities, were submitted to me for microscopic examination. Inspection led to the conclusion that the rock was composed so largely of organic residues, that it would be practicable to apply to it methods of sectioning already in use for making thin sections for the microscopic study of peats and coals.

After some experimental work, it was found possible so to soften the material without any visible change in its original form or structure, that after it was imbedded in paraffin, sections could be made from it with razor or microtome as readily as from properly prepared fresh vegetable tissue. Sections of any desired thinness can thus be made, and in any quantity. Moreover, these sections can be so treated that when mounted they can be studied with the highest powers of the compound microscope.

Several highly interesting and important facts have been discovered by examining specimens of the shale prepared as outlined above. The ground mass of the sections was found to be of the nature of a somewhat granular, organic jelly, closely resembling in optical properties, some of the structureless, colloidal or sapropelic peats, solidified and compacted into a dense, tough, impermeable magma.

Apparently the hardening and compacting of this material from its original gelatinous condition to its present state, was a process of slow dehydration and contraction, without any violent disturbance or action of any outside metamorphosing agencies. This is shown by the undisturbed position and structure of the shale beds in the mass, as well as by the almost entire lack of visible changes in the delicate plant structures that are often abundant in the sections examined.

The ground mass, magma, or body of the shales, from its structure as seen under the microscope, seems to have been originally vegetable matter. It apparently was a mixture of finely divided and flocculent plant debris and living microscopic plants, bacteria, etc., most of which probably were more or less saprophytic, decomposing and still farther disintegrating the mass of detritus in and on which they lived.

Imbedded in this magma, as many of the sections showed, are innumerable plant cells, structures, and entire plants, almost as perfectly preserved as if they had been prepared by the most refined methods of the plant morphologist. Many of these fossils are spores, fungi or structures belonging to the higher plants, but a large percentage of them are clearly Algae of low types. Three distinct types of Algae have been discovered by the work so far done.

1. A very considerable number of cellular, filamentous and gelatinous forms, which, from their methods of reproduction and general morphology, are clearly to be placed with the Blue-Green Algae—(*Myxophyceae* or *Schizophyceae*). These include forms that show close relationship to modern types of these low Algae, not only in size and vegetative structure, but also, many of them show a series of reproductive stages so characteristic as to fully establish their taxonomic relationships. In one instance at least, a minute but highly characteristic blue-green Alga has been found that can almost certainly be referred to a living genus, namely *Spirulina*. This fossil specimen is so well preserved and the measurements and form of the plant are so closely in harmony with those given in descriptions of one of the species of the genus, that one is tempted to identify the fossil as belonging to the same species, notwithstanding the hundreds of thousands of years which must have elapsed since the Eocene time. Other fossil species that may be referable to existing genera are not uncommon.

2. The Yellow-Green Algae (*Chlorophyceae*). Somewhat less common than the low forms already mentioned are plants that can be referred with more or less certainty to the Green Algae. Among these, both the cellular and filamentous types have been discovered, and, in a few cases, the identification may be said to be positive. Among cellular forms, is one in particular that so closely resembles a species of *Pediastrum* in all essentials, that its reference to this or a closely related genus is clearly not an error.

Among the filamentous fossil forms classed as Green Algae, a type has been noted with spiral chloroplasts, so like those which characterize the well-known *Spirogyra*, that it appears at least to be a prototype, if not strictly a species of this genus. Other filamentous fossil species have been found which, because of structural peculiarities, can be safely placed among the Green Algae.

3. Unclassified Algae. A large number of plants have been found, which, from their form and structure, appear to be Algae, but which as yet, cannot be classified among known living Algae. Some of these unclassified types are the largest plants so far found in the shales, and others are very minute. Some of the more noteworthy of the large forms seem to have been thin, gelatinous films growing on the surface of the detrital material which is now the imbedding magma.

A very common and puzzling plant is one of the gelatinous film-like forms of considerable size, which seems to be without cellular structure, but which, nevertheless, has small areas on its surface which on magnification disclose definite, usually oval, spots covered with a net-like pattern formed by small crowded hexagonal depressions on the surface of the film. The meaning of these netted areas has not yet been worked out, but it seems possible that the structure is a reproductive surface from which spores arise. The whole plant after most careful examination seems to have been made up of gelatinous material forming a thallus, with no definite divisions into cells.

Besides the filmy gelatinous types, there are large numbers of seemingly gelatinous forms that were more or less filamentous. These types vary greatly in the length and width of their filaments, which are often more or less flattened, and which branch in an eccentric way, quite unusual among the modern Algae. The filaments lack visible divisions into definite cells and seem to have been wholly gelatinous or to have been sheathed by thick gelatinous envelopes, which have obliterated the evidences of cell division.

It is well known, however, that we have very slight and indefinite knowledge of the floras of present-day fresh and salt waters, especially of those which grow in and around the deeper parts of waters in which there are deposits of organic origin, and many of the plants which have been described from shallow waters are so imperfectly known that their life histories have never been worked out. These facts make the study and classification of fossil forms much more difficult than it would otherwise be, and their relationships harder to determine.

Careful study of the material under discussion indicates how perfectly plant remains, originally of the most delicate structure, have been preserved. Even very thin-walled and fragile cells and filaments show by internal evidence that they did not even collapse as they were incorporated into the mass in which they are preserved. Contraction, caused by shrinkage from the loss of water in the original substances, and the later changes which have transformed them into rock, has manifestly occurred. Dehydration has been so slow and regular, however, that it has produced no changes that have in any way interfered with the microscopic study of the properly prepared material. The perfection of the preservation of the plant remains in these rocks is such that it is quite evident that, with such specimens to work with, there need be no difficulty in learning the facts or in fully and correctly interpreting them. All doubt as to the possibility of Algae, and similar cellular plants of most delicate structure being preserved and their remains becoming a conspicuous part of the organic matter found in carbonaceous rocks is removed by the studies here recorded.

The discovery of this interesting flora of minute fossil Algae, doubtless the most extensive of its class yet reported, embracing as it does thousands of individuals and an undetermined number of species, many of which have not yet even been photographed, is in itself a noteworthy matter. The discovery seemingly has a more important bearing, however, on the broad geologic problem of the origin and development of petroleum and related carbonaceous compounds, than it has on that of the development of plant life.

Several steps looking towards the solution of this great genetic problem have been taken already and tentative advances have been made. The structure of the rock, the kind of fossils in it, and their state of preservation, make it possible to determine, to some extent at least, the sources of the abundant carbonaceous matter which it contains, and the conditions under which this matter accumulated. The state of decomposition of the original organic substance contained in the magma has, to some extent, to be assumed, since it is so largely structureless. It is practically certain from studies made on peat, that the breaking down of the original structure of this material is rather a physical than a chemical change, a comminution, not a decomposition. The true chemical condition of the organic matter of the rock is more correctly interpreted from the fossils, which probably are approximately at the same stage of carbonization as the structureless magma. The chemical condition of the finely preserved fossils, therefore, becomes highly significant, this, judging from their color, physical condition, etc., is indicative of very early stages of carbonization, which in turn, shows a very limited action by the transforming agencies originating within the earth itself, i.e., those producing metamorphism.

Finally, and of great importance in the consideration of the larger problem, is the determination of the actual substances now existing in the rock itself, from which the distillates obtained by heating, are derived. It will readily be seen that this constitutes a somewhat prolonged investigation but it is easily within the reach of modern chemical science.

It can already be stated positively that the organic matter of these shales, so far as examined, in very large part is of vegetable origin, with but very slight traces of the remains of animal organisms. The plant remains were accumulated in water of considerable depth and purity and in places apparently remote from shore lines. To a considerable extent this vegetable matter seems to have been of the nature of drift material or plankton, although it is largely mixed with the remains of Algae and similar plants that certainly grew upon and in the magmatic mass as a place of attachment, if not actually aiding in its decomposition by their growth.

The beds thus formed were built up very slowly, and when completed and solidified were so compact and fine grained as to be nearly or quite impermeable to liquids from the outside. If infiltrated by any material from without before the water originally included was drained and dried away, it is difficult to see how this could be done by liquids lighter than water, coming into it in the form of a uniform seepage from below. Exactly contemporaneous with the gradually progressive disappearance of the water and the chemical changes accompanying this, the sediments were compacted, solidified and lithified to their present texture and condition, and it seems highly probable that penetration by liquids from any outside source during the induration would be increasingly difficult. If these views are correct, the gaseous and liquid compounds obtained by distillation from the shale are not of external origin, but result from the decomposition of the carbonaceous material laid down during the formation of the rock. The absence of demonstrable liquid hydrocarbons in the shale itself would tend to strengthen this view, although not an insurmountable objection.

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ARCHEOLOGICAL EXPLORATIONS AT PECOS, NEW MEXICO

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During the past summer the Department of Archaeology of Phillips Andover Academy began the excavation of the ruined Indian Pueblo of Pecos in San Miguel County, New Mexico. It was the wish of the Department to undertake the thorough exploration of a site large enough and of sufficient scientific importance to justify work upon it for several years.

Pecos lies in the well-watered and fertile upper Pecos valley at an elevation of about 7000 feet. The buildings are located on the summit of a flat-topped ridge of sandstone slightly elevated above the surrounding plain, and consist of two house-clusters containing together, as nearly as can be made out in their present state of ruin, about 1100 ground floor rooms. A few hundred feet to the south stand the roofless walls of the large Spanish mission church.

The place was discovered by Coronado in 1540. At that time it was the most populous of the Pueblo villages, being able to muster 500 fighting men. The chroniclers of the expedition describe the town as a quadrangular structure, four stories in height, on the balconies of which